Robust Self-Configuring Embedded Systems
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Software Architectures for Graceful Degradation in Embedded Systems

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Software Architecture for Graceful Degradation

- **Introduction**
  - Software architecture and embedded systems
  - Graceful degradation
  - RoSES product family architecture
- **Example system: an elevator architecture**
  - Elevator Functionality
  - System sensors/actuators
  - Standard elevator architecture
  - Preliminary architecture for graceful degradation
- **Architectural concerns and evaluation**
- **Summary**
- **Future Questions**

Software Architecture for Embedded Systems

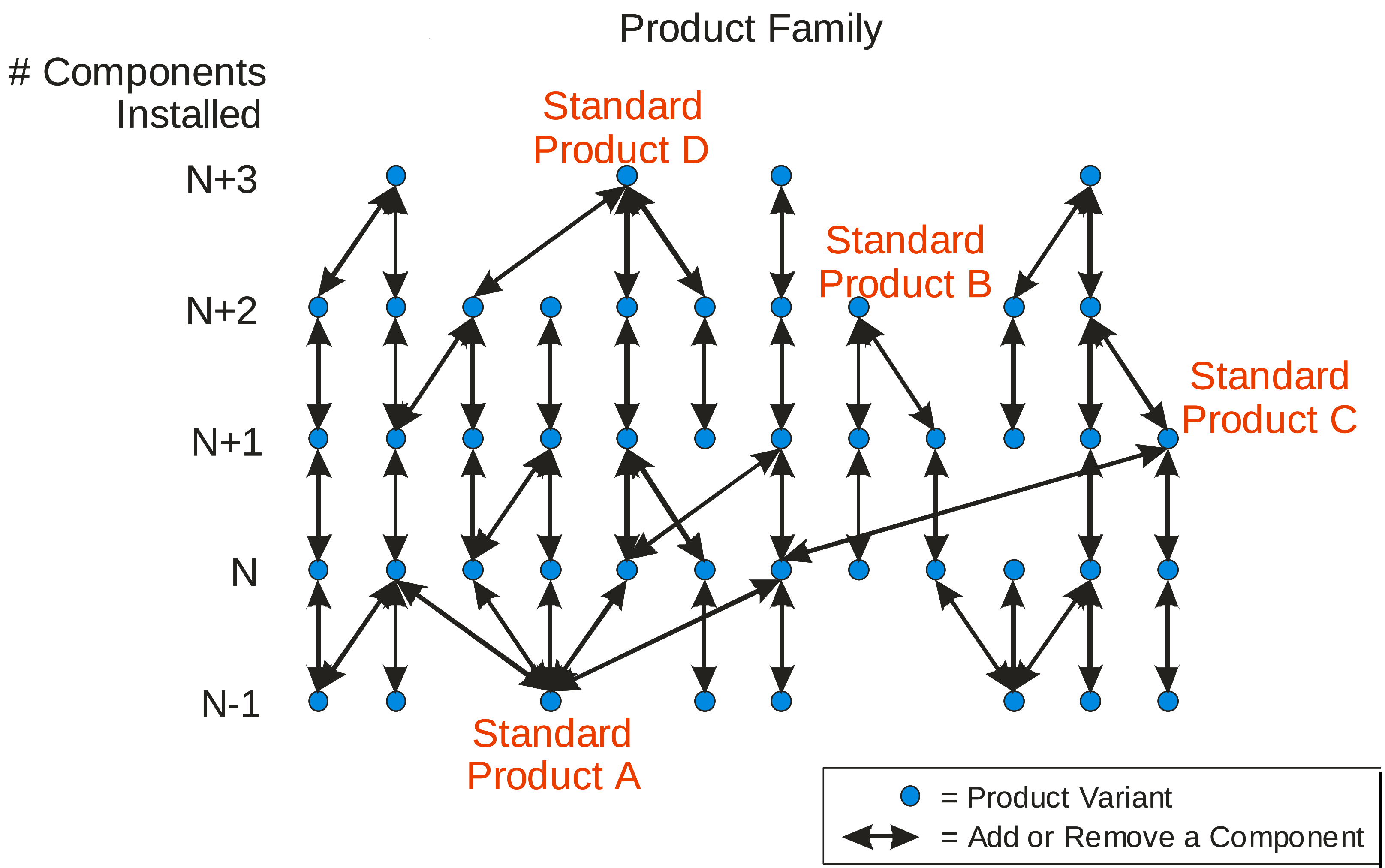
- **Can we develop software architectures to promote graceful degradation in embedded systems?**
- **Software Architecture**
  - Overall structure of system
  - Decompose system into components and connectors
  - Provide ability to reason about system at high level
  - Several architectural styles/patterns have been identified
- **Embedded Systems**
  - Added system complexity/features is driving larger, more complex software
  - Safety-critical, dependability
  - Limited hardware resources, extremely cost-sensitive
  - Traditional software architectural styles may not be appropriate

Graceful Degradation

- **Individual component failures reduce functionality; do not cause system failure**
  - Method to achieve robustness, safety, dependability
- **Goal: Achieve graceful degradation without explicitly specifying all failure scenarios a priori**
  - How can the system's software architecture influence graceful degradation?
- **Possible approaches**
  - Highly distributed
  - No single point of failure
  - Components are decoupled and autonomous
  - Redundancy (not as effective for software)
- **Case Study: Elevator System**

RoSES Product Family Architecture

- Different component configurations provide certain levels of functionality
- Specify architecture with minimum functionality as base configuration
- Focus on architecture for valid component configurations, not reconfiguration problems (Bill Nace's work)

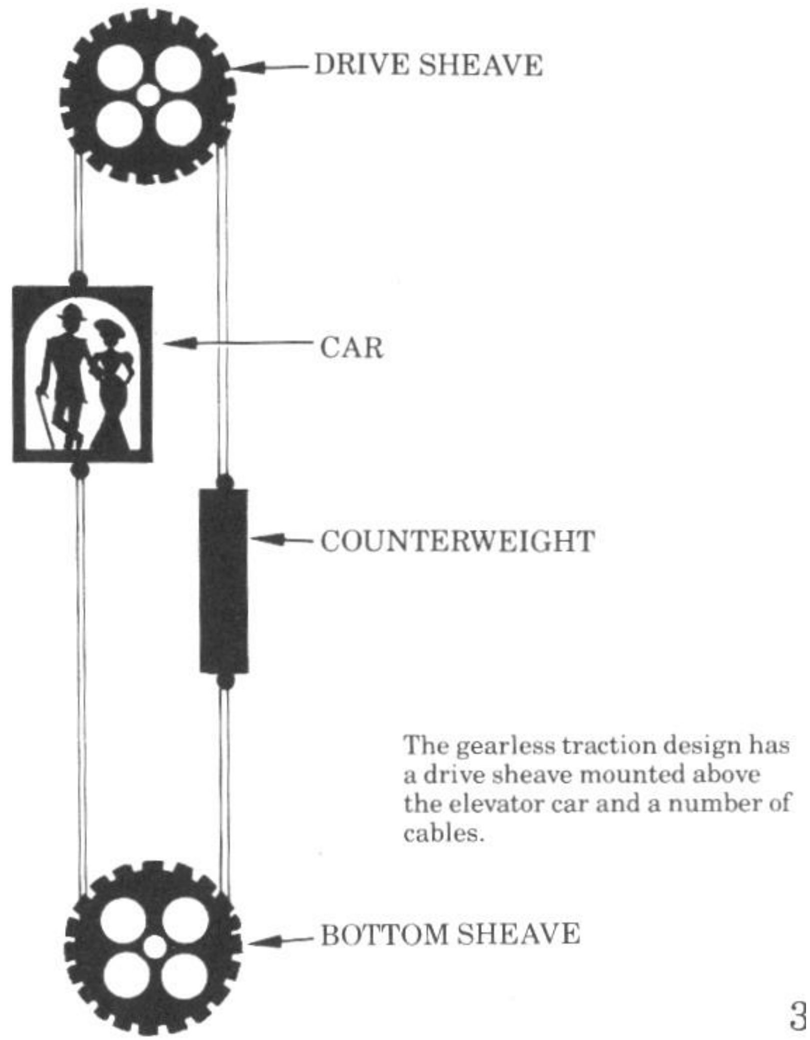


Architectural Decisions

- **Explicitly specify component interfaces**
  - Construct all possible messages to be passed between components
  - Helps determine which components need to communicate
- **Partition Functionality**
  - Separate critical and non-critical functionality
  - Make critical components as autonomous as possible
- **Constrain component configurations**
  - Each component has minimal input/output interface
  - Critical components must be present for base functionality

Elevator Functionality

- **Must transport people between floors**
  - Move car slowly in shaft
  - Stop at every floor
  - Open doors at each floor
- **Must ensure safety**
  - Do not crush people between doors
  - Do not crush people between floor and elevator
  - Do not run car at unsafe speeds
  - Do not trap people in the elevator
- **Optimizations**
  - Only stop on requested floors
  - Provide feedback to passengers
  - Minimize travel time, wait time



Elevator System Sensors and Actuators

Sensors

- Elevator position and speed
  - AtFloor[f,d](v)
  - HoistwayLimit[d](v)
  - DriveSpeed(s,d)
- Door sensors
  - DoorClosed[j](v)
  - DoorOpen[j](v)
  - DoorReversal[j](v)
- Passenger requests
  - CarCall[f](v)
  - HallCall[f,d](b)

Actuators

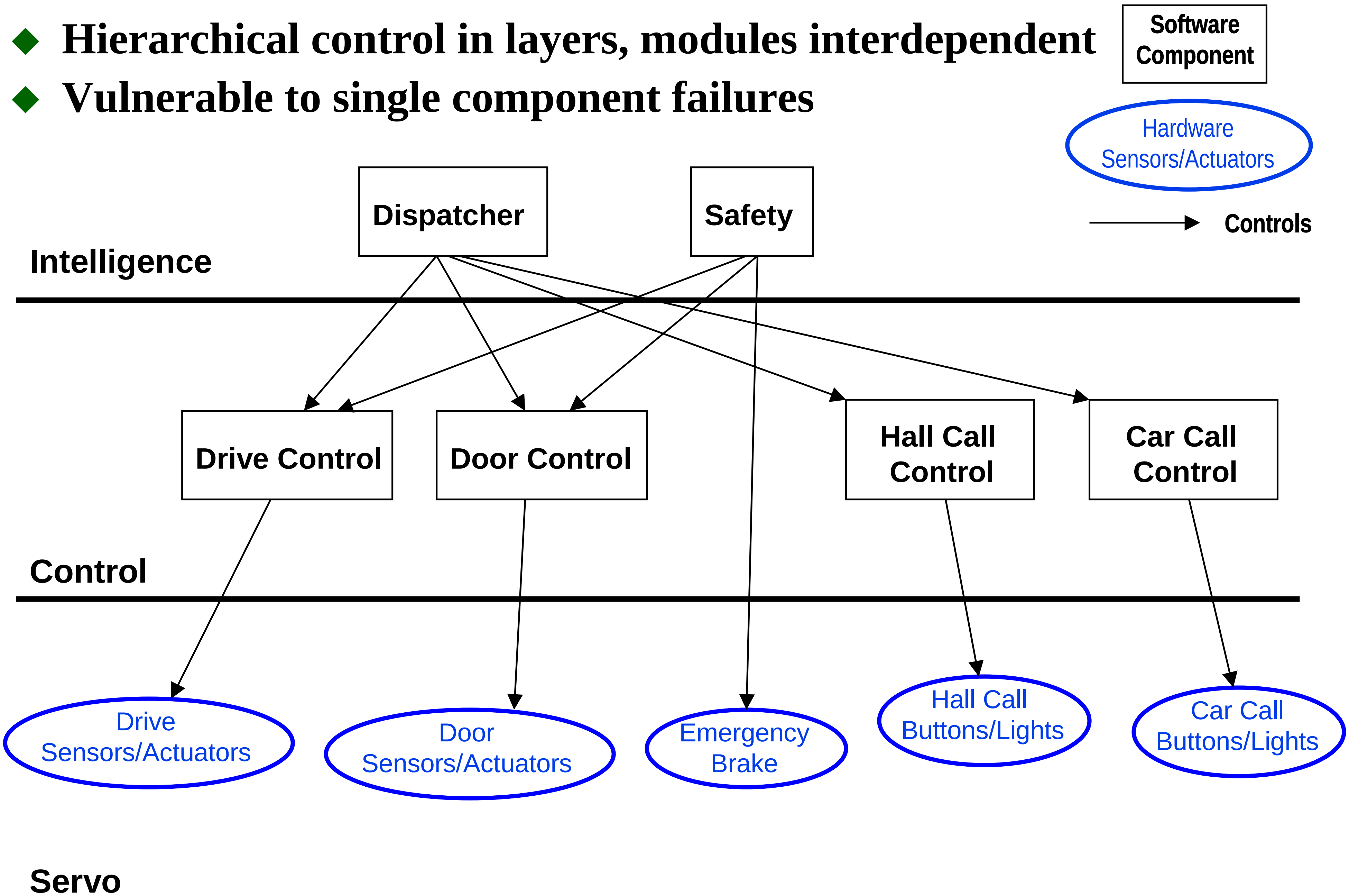
- Elevator control
  - DoorMotor[j](m)
  - Drive(s,d)
  - EmergencyBrake(b)
- Button lights
  - CarLight[f](k)
  - HallLight[f,d](k)
- Passenger feedback
  - CarLantern[d](k)
  - CarPositionIndicator(f)

Control System State

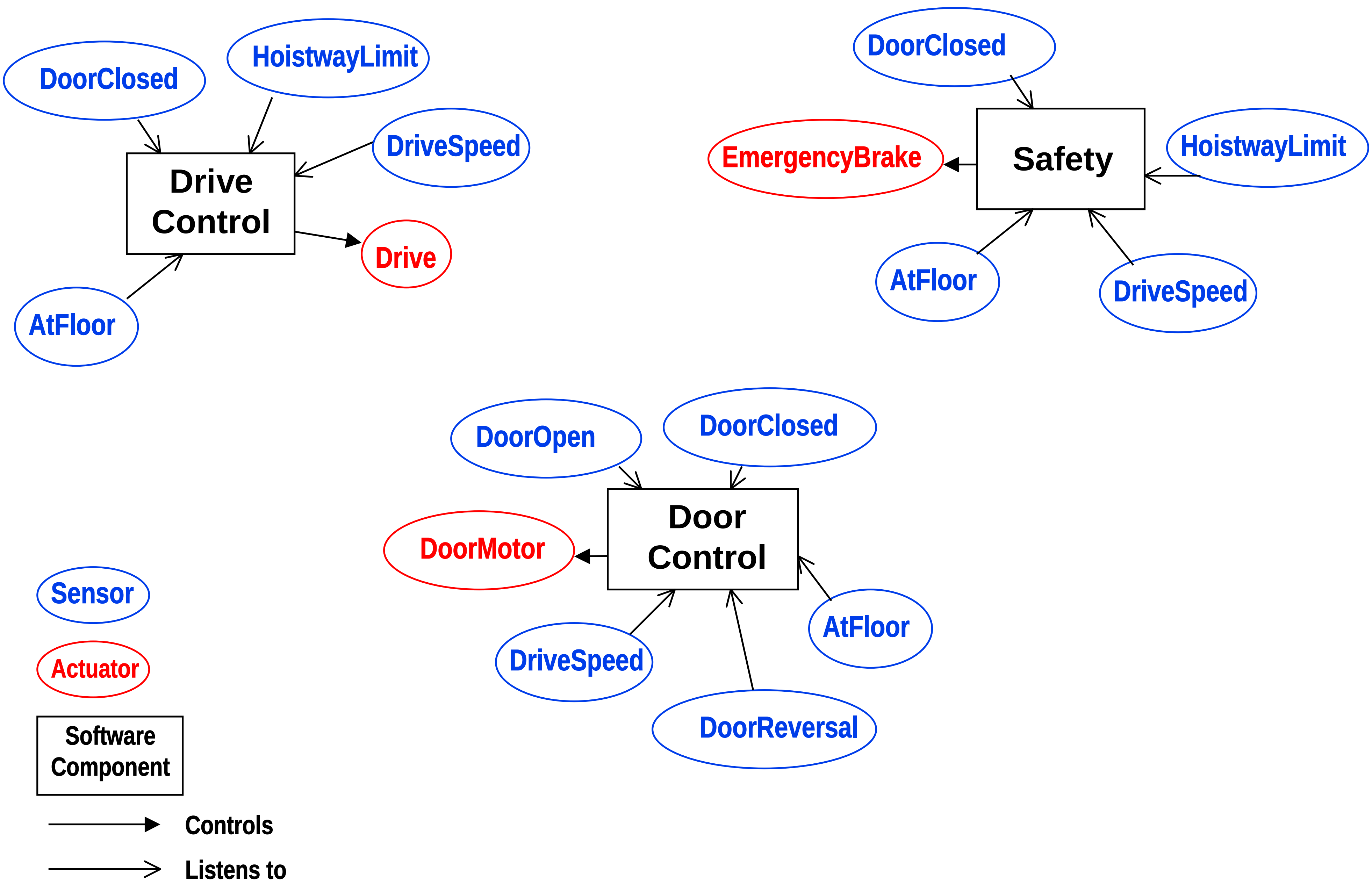
- DesiredFloor(f,d)
- DesiredDwell(n)

Standard Elevator Control Architecture

- Hierarchical control in layers, modules interdependent
- Vulnerable to single component failures

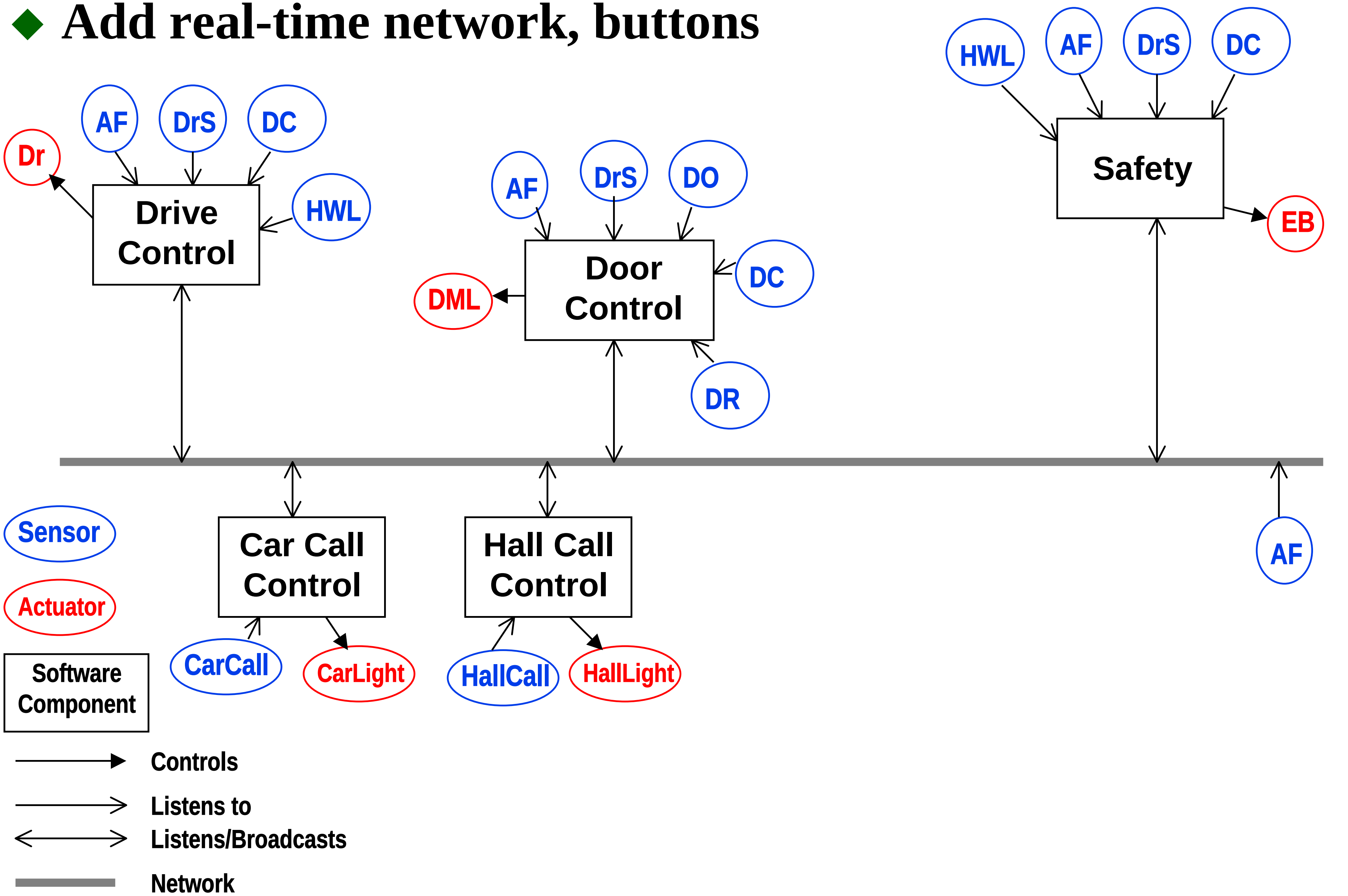


Elevator Architecture: Product 1 (Base)



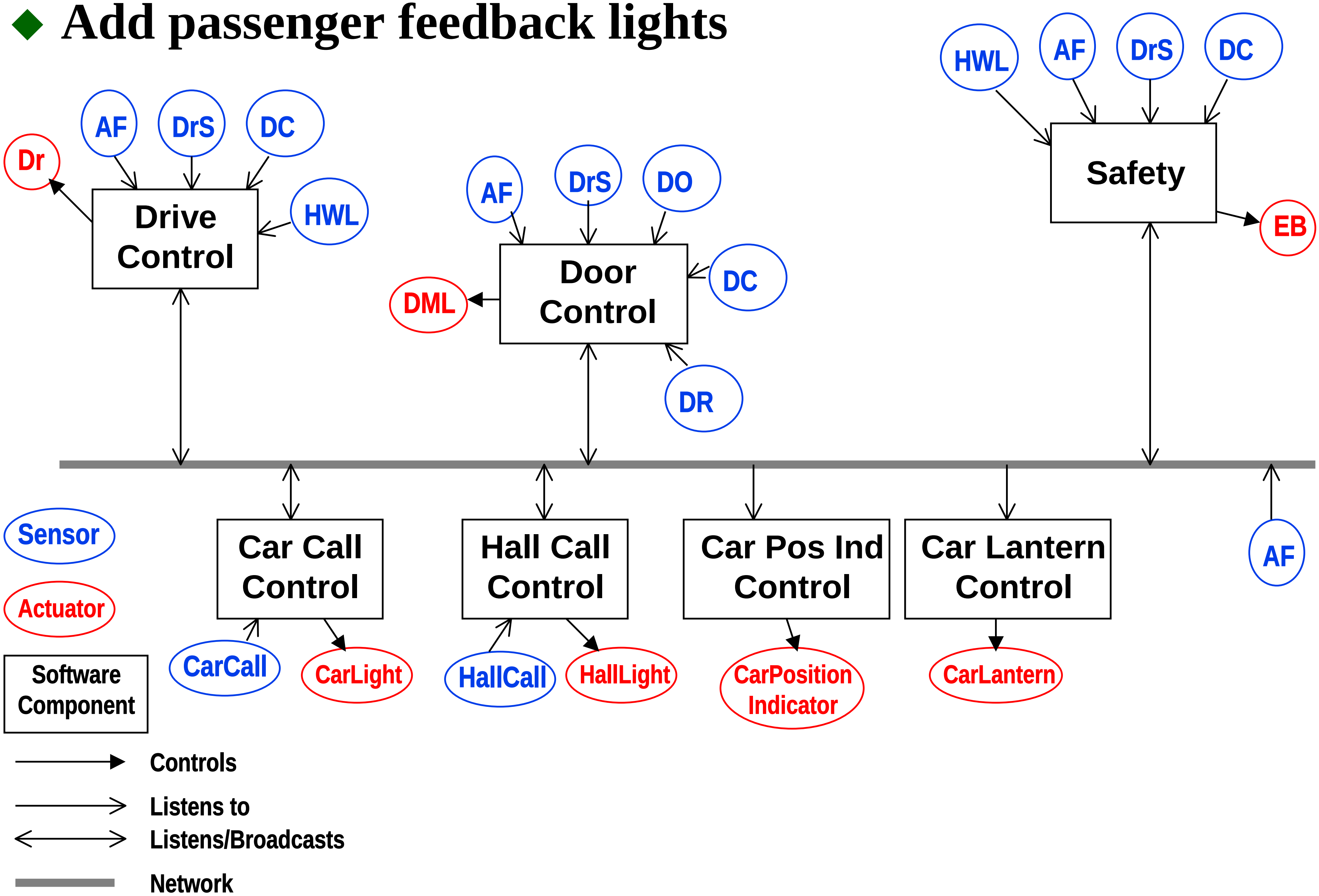
Elevator Architecture: Product 2

- Add real-time network, buttons



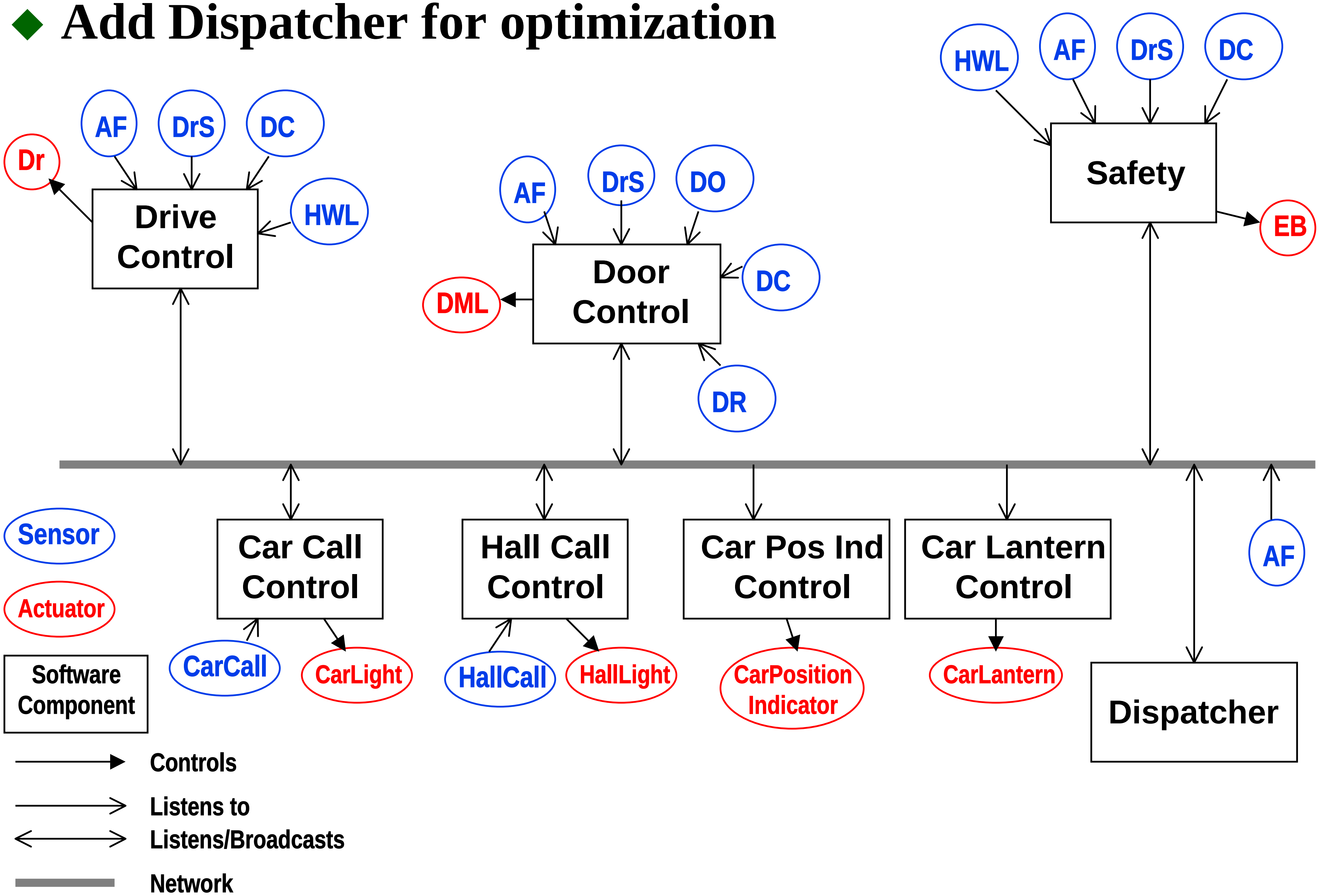
Elevator Architecture: Product 3

- Add passenger feedback lights



Elevator Architecture: Product 4

- Add Dispatcher for optimization



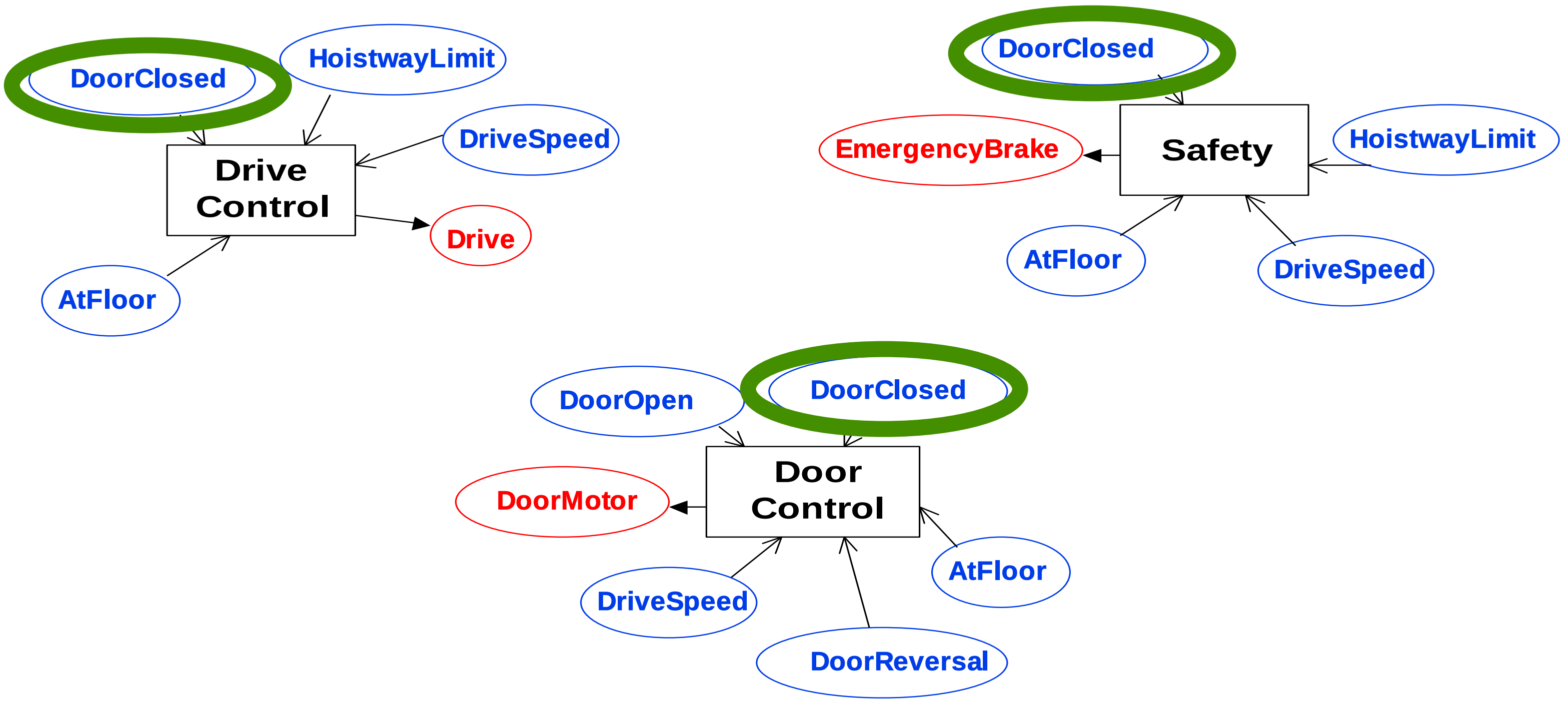
Elevator Control System

- **Main controllers are autonomous**
  - Drive Controller
  - Door Controller
  - Safety
- **Other controllers provide “advisory” information**
  - HallCall buttons
  - CarCall buttons
  - Dispatcher
- **Main controllers follow advice when available**
  - Must pass internal consistency checks
  - In absence of advice, perform base functionality

Architectural Concerns (1)

◆ Cost vs. Safety/Dependability

- Adding additional redundant sensors
  - Necessary to ensure safety for main controllers
  - Could add more for each secondary controller, but cost prohibitive



- Network
  - Could be a single point of failure
  - Without it need exponentially more sensors for more features
  - Could add secondary network to increase dependability

Architectural Concerns (2)

- **Abstract sensor/actuator interface for components**
  - Components can access sensors from physical link or network without modifying code
  - Logical interface separates software concerns from hardware concerns
- **System Configurations**
  - Designed into architecture to constrain configuration options
  - Reconfiguration “hardwired”
  - System should survive components failing in arbitrary order

Evaluation

- **How can I evaluate my architectural design?**
  - Can’t build working elevator and test it
  - Simulation of a distrbuted network
- **Simulation framework exists from ECE 540/549 class**
  - Build executable system from my architecture
  - Fault injection mechanisms to fail components during system operation
  - Measure performance delivering passengers for each configuration

Summary

- **Embedded Systems need methods to ensure safety, dependability, robustness**
  - Graceful Degradation
- **System's software architecture may strongly influence whether graceful degradation is achievable**
- **Design a software architecture for an elevator system**
  - Distributed
  - Decoupling of components
  - Product family structure
  - Some hardware replication
- **Build executable system and test it**
- **How well does it promote graceful degradation?**

Future Questions

- **Can we develop an architectural style specifically for graceful degradation?**
  - Embedded systems have special concerns
    - Cost
    - Constrained resources
- **Can we apply it to multiple domains?**
  - Elevator
  - Automobile navigation system
  - Drive-by-Wire